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AN EVALUATION OF AN ACCELEROMETER METHOD FOR

OBTAINING LANDING-GEAR DRAG LOADS

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SUMMARY

An accelerometer method for obtaining landing-gear drag loads was
evaluated for a series of landings with a small landing gear in the
Langley impact basin. The drag loads were obtained from time histories
of angular acceleration of the wheel, the moment of inertia, and-the
deflected tire radius. The method involved the use of an angular accel-
erometer, a torsional pendulum for determining moment of inertia, and
linear accelerometers to measure the vertical forces (from which were
obtained the force-deflection characteristics of the tire).

The results obtained with this method were in good agreement with
the results obtained simultaneously from specially constructed dynamometers.
This agreement indicated that, under the conditions of this investigation,
the applied drag loads can be obtained accurately by use of this method
and that the deflected tire radius can be obtained from the static-force—
deflection curve of the tire up to and including the time of maximum drag.

INTRODUCTION

The magnitude and variation of the wheel spin-up drag load during
landing have a significant influence on the required strength of an air-
craft landing gear and the adjacent structure. Because this load is
applied by the ground to the wheel during the very brief time required
for the wheel to reach test speed, accurate experimental measurement of the
time history of this load is difficult. The usual strain-gage instru-
mentation applied to the landing gear is subject to the effects of
interaction and hysteresis and, moreover, the results require correction
for inertia effects arising from the elastic response of the structure.
Furthermore, the installation of the instrumentation is very time con-
suming and expensive.

A method for obtaining drag loads by use of accelerometers now appears
to be practical because angular accelerometers of the range and frequency
necessary have become available. With this method, the drag load is
calculated from the wheel angular accelerations, moment of inertia, and
the deflected tire radius, the latter being obtained from the vertical

load on the tire, as determined from linear accelerometers and the known force-deflection characteristics of the tire.

In order to evaluate the method, a series of simulated landings was made in the Langley impact basin with a main landing gear from a small trainer-type airplane. The results obtained with the accelerometer method were compared with data obtained simultaneously from a strain-gage dynamometer on the landing-gear axle.

APPARATUS AND INSTRUMENTATION

The investigation was conducted in the Langley impact basin (ref. 1) by utilizing a removable concrete runway installed to permit the testing of landing gears with forward speed (fig. 1). The landing gear was attached to the drop linkage of the impact basin carriage (fig. 2). This equipment provides means for effecting the controlled descent of the landing gear while the carriage is either stationary or moving horizontally. A complete description of the carriage as adapted to the testing of landing gears is given in references 2 and 3.

The landing gear was one of the two main gears of a small trainer-type airplane having a gross weight of approximately 5,000 pounds. The gear was of cantilever construction and incorporated a standard-type oleo-pneumatic shock absorber. This landing gear, however, was altered to include a specially constructed dynamometer mounted between the wheel axle and the fork of the landing gear as shown in figure 3. The wheel was equipped with a 27-inch smooth-contour (type I) tire having a nonskid tread.

A commercial angular accelerometer having a range of 0 to 4,000 radians per second per second and a natural frequency of 135 cycles per second was mounted at the center of the wheel as shown in figure 4. The sensitive element of the accelerometer consists of a torsionally suspended mass which is displaced angularly with respect to the instrument case when subjected to angular acceleration. The relative motion of this mass produces proportional changes in the output of an inductive element which are then transmitted through slip rings on the wheel hub to an oscillograph. The mass is mechanically balanced so that the response to linear acceleration is negligible. A torsional pendulum was used to obtain calibration and frequency-response data on the instrument. The same torsional pendulum was used to determine the moment of inertia of the wheel and tire assembly (see fig. 5).

Three linear unbonded-strain-gage accelerometers were mounted on the test apparatus as shown in figure 3. An accelerometer having a natural frequency of 125 cycles per second measured the vertical accelerations of

the upper mass. An accelerometer having a natural frequency of 150 cycles per second was mounted on the fork of the landing gear and measured the lower mass accelerations along the axis of the strut. Another accelerometer having a natural frequency of 850 cycles per second measured the lower mass accelerations normal to the strut axis.

The dynamometer connecting the wheel axle to the landing-gear fork measured the component of load transmitted from the axle to the fork along the axis of the oleo strut as well as the component normal to this axis. The load-measuring elements of the dynamometers consisted of strain gages mounted on suitably oriented beams. The output of the dynamometer was interpreted in terms of the applied ground load by the application of inertia corrections to account for the elasticity of the landing gear. These inertia corrections were derived from acceleration measurements obtained on the lower mass. Measurements of the ground loads obtained in this manner during stationary drop tests with wheel spin-up check very closely with those obtained at the same time from a ground-reaction platform (ref. 3). The ground-reaction platform (fig. 6) consists of a concrete surface mounted on a rigidly anchored truss work containing strain-gage members capable of measuring loads in the vertical and drag directions. Tire-deflection measurements were obtained by measuring the displacement of the upper mass as well as the relative displacement (shock strut stroke) between the upper and lower masses. The difference between these two displacement values is the tire deflection. Both displacement measurements were obtained by means of variable-resistance slide-wire potentiometers. The slide-wire potentiometer used to measure the upper-mass displacement is described in reference 1 and the slide-wire potentiometer used to measure the strut stroke is shown in figure 3. All accelerometers and recording galvanometers were damped to approximately 0.65 critical damping.

TEST PROCEDURE

The data were obtained from 28 landing impacts made at forward speeds ranging from 18 feet per second to 85 feet per second and vertical velocities ranging from 3 feet per second to $9\frac{1}{2}$ feet per second. In addition, several stationary drop tests with the wheel spinning were made onto the ground-reaction platform. The stationary drop tests were made at a vertical velocity of $7\frac{1}{2}$ feet per second and a wheel angular velocity at contact of 850 revolutions per minute. The inclination of the landing gear to the vertical axis was fixed at 15° (nose up) throughout the forward-speed landing impacts but was reduced to 0° for the drop tests. All landings were made at a dropping weight of 2,500 pounds. Throughout the impact tests, a lift force equal to the total dropping weight was exerted on the landing gear by means of the lift engine described in reference 2.

RESULTS AND DISCUSSION

The values of landing-gear-wheel spin-up drag load were obtained by using the following expression:

$$F = \frac{I\alpha}{r}$$

where the symbols are defined as follows:

F   instantaneous wheel spin-up drag load

I   moment of inertia of wheel and tire

α instantaneous angular acceleration

r   deflected tire radius, distance from axle center line to runway

The angular accelerations throughout the spin-up process were obtained directly from the angular accelerometer. Although this method assumes the wheel and tire to be a rigid body, it is known that the tire is not completely rigid when subjected to fore-and-aft loading. When the drag loads are determined from the angular-acceleration measurements, the possibilities of error from torsional oscillations of the outer portion of the tire and from changes in moment of inertia because of tire deflection were considered. On the basis of preliminary calculations, however, both errors appear to be negligible up to and including the time of peak drag load.

The deflected tire radii were obtained by use of instantaneous vertical loads computed from acceleration time histories of both the upper and lower masses. If a time history of vertical load on the tire is known, the instantaneous tire deflection and, thus, the instantaneous radius can be determined from a force-deflection curve for the particular tire under consideration. The dynamic-force—deflection curve should be used in this procedure, inasmuch as it is generally true that, under dynamic conditions, the tire acts stiffer than under static conditions. However, several dynamic-force—deflection curves obtained during these tests were compared with the static-force—deflection curves and very good agreement was obtained from the instant of initial ground contact up to the time of maximum drag load; the static-force—deflection curves therefore were used to determine the instantaneous tire radius.

Figure 7 shows such a comparison for a drop test with the wheel spinning, and figure 8 shows a similar comparison obtained during forward-speed landing impacts at various horizontal velocities. In figure 9, the

values of tire radii at peak drag load obtained during all the landing
impacts are compared with tire radii at peak drag load from static-force—
deflection curves, and good agreement is obtained. The agreement observed
up to the time of maximum drag load is believed to result from the presence
of drag load which produces additional deflections (ref. 4) which appar-
ently compensate for the additional stiffness normally found in the tire
under dynamic conditions. Immediately after the instant of peak drag load,
however, the drag load decreases very rapidly and the tire exhibits the
stiffer load-deflection characteristics associated with dynamic conditions
(as shown in figs. 7 and 8). Inasmuch as it appears that the drag load
has an effect on the tire deflection, the agreement between dynamic- and
static-force—deflection curves might be lessened if the values of the
coefficient of friction were much different from the values which occurred
in these tests.

When the vertical load was calculated, the inclination of the
landing-gear strut made it necessary to measure the accelerations parallel
and normal to the strut axis and to sum up the vertical components.
Examination of the data, however, reveals that, in the case of the par-
ticular gear tested, the vertical component of the strut normal acceler-
ation was small up to and including the time of maximum drag load. This
condition is illustrated in figure 10 which shows two sets of typical
time histories of the vertical load, drag load, and vertical component
of the strut normal acceleration. Therefore, for purposes of determining
tire deflections during the spin-up process, the vertical component
of the normal acceleration was omitted in this case and only two accel-
erometers were used to determine the vertical load, even though the strut
was inclined.

The applied drag loads in the present investigation were obtained
from the accelerometer measurements during spin-up drop tests as well as
during forward-speed landing impacts. The results are compared with the
loads obtained from the ground dynamometer for a representative spin-up
drop test and with the loads from the axle dynamometer during the forward-
speed landing impacts. Figure 11 presents data from a representative
spin-up drop test and shows that the time history of the applied ground
drag loads obtained from the acceleration measurements agrees very closely
with the ground-reaction-platform results. In figure 12, a comparison
of drag-load time histories derived from the accelerometers and the axle
dynamometer also reveals very good agreement for the forward-speed landing
impacts. Figure 13 shows a comparison of the maximum drag loads derived
from the angular-accelerometer measurements and the maximum drag loads
derived from the axle dynamometer for all the forward-speed landing impacts.
It can be observed that the data fall very closely along the line of
perfect agreement. The fact that good agreement was obtained in these
comparisons (figs. 11 to 13) indicates that, under the conditions of this
test which includes spin-up drop tests as well as forward-speed landing
impacts, the applied ground drag loads can be obtained accurately from
the outputs of an angular accelerometer and two linear accelerometers.

The data obtained in these tests also yield results that indicate
the possibility of using the linear accelerometers for measuring the
complete time history of the vertical load applied to the landing-gear
wheel at the ground. During these tests, the maximum vertical load
occurred after the maximum drag load; therefore, the component of vertical
acceleration derived from the lower mass normal accelerometer is appreci-
able and must be included in calculating the vertical load (fig. 10).
Figure 11 contains data obtained from a drop test and shows a comparison
of the vertical-load time histories obtained from the ground-reaction
platform and from the three linear accelerometers. Figures 14 and 15
present a similar comparison for forward-speed landing impacts. The
agreement between the time histories obtained from the dynamometers and
those derived from the accelerometer measurements appears to be good.
Data from all the forward-speed landing impacts are collected in figure 16
which compares maximum vertical loads from the axle dynamometer with the
maximum vertical loads from the accelerometers. These comparisons also
show agreement and indicate that, under the conditions of this test, the
determination of vertical load by means of accelerometer measurements
yields reliable results.

CONCLUSIONS

An evaluation was made of landing-gear-wheel spin-up drag loads
obtained from an angular accelerometer, the moment of inertia of the
wheel, and the deflected tire radius. The data were obtained during
simulated forward-speed landing impacts and drop tests on a concrete
runway at the Langley impact basin by using a small oleo-pneumatic landing
gear held at fixed trim. From the results of this investigation, the
following conclusions may be drawn:

1. Applied drag loads can be obtained with good accuracy from time
histories of angular acceleration of the wheel, the moment of inertia,
and the deflected tire radius as obtained from the force-deflection
characteristics of the tire (by using linear-accelerometer measurements
for the vertical force).

2. Vertical loads could be obtained accurately by use of linear
accelerometers.

3. Under the conditions of this investigation, the static-force—
deflection curve for the tire could be used to determine the tire
deflection up to and including the time of maximum drag load during
landing impacts.

Langley Aeronautical Laboratory,
    National Advisory Committee for Aeronautics,
   Langley Field, Va., July 16, 1954.

REFERENCES

1. Batterson, Sidney A.: The NACA Impact Basin and Water Landing Tests of a Float Model at Various Velocities and Weights. NACA Rep. 795, 1944. (Supersedes NACA WR L-163.)

2. Milwitzky, Benjamin, and Lindquist, Dean C.: Evaluation of the Reduced-Mass Method of Representing Wing-Lift Effects in Free-Fall Drop Tests of Landing Gears. NACA TN 2400, 1951.

3. Milwitzky, Benjamin, Lindquist, Dean C., and Potter, Dexter M.: An Experimental Investigation of Wheel Spin-Up Drag Loads. NACA TN 3246, 1954. (Supersedes NACA RM L53E06b, 1953.)

4. Horne, Walter B.: Static Force-Deflection Characteristics of Six Aircraft Tires Under Combined Loading. NACA TN 2926, 1953.

Figure 1.- Concrete runway installation in Langley impact basin.

L-62850
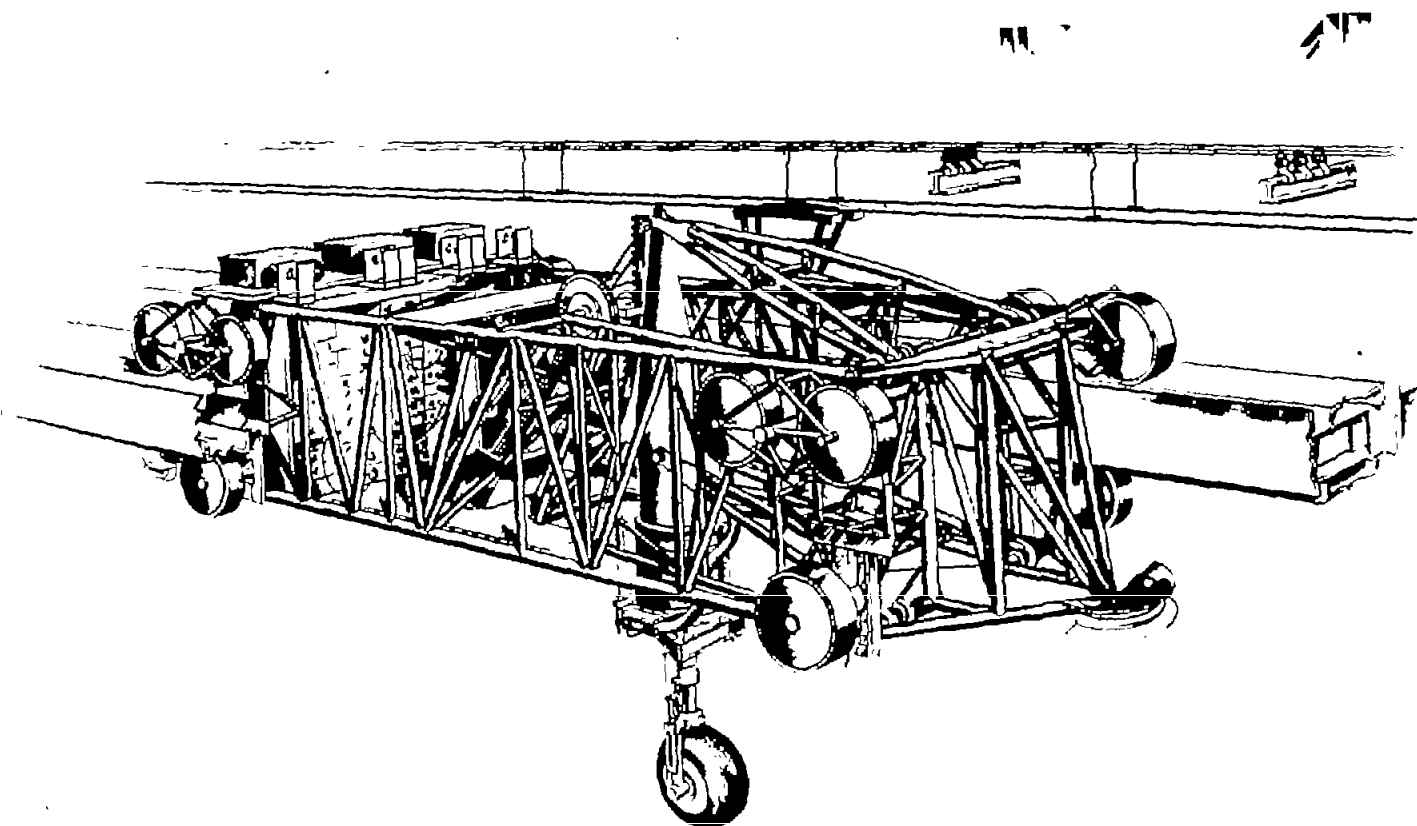
L-59596

Figure 2.- Langley impact basin carriage adapted for landing-gear testing.
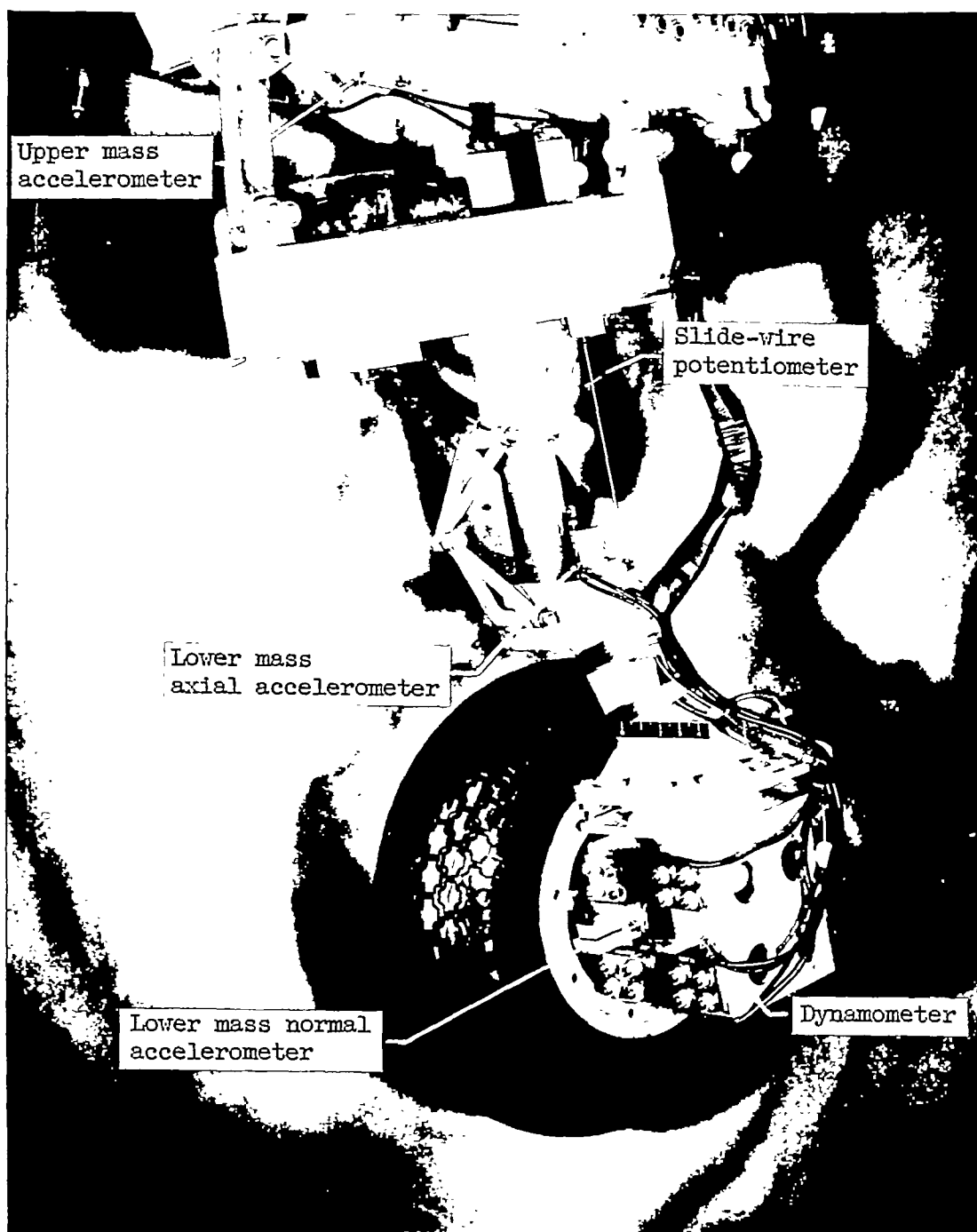
Figure 3.- Rear view of landing gear attached to carriage boom in   L-80402.1
Langley impact basin.
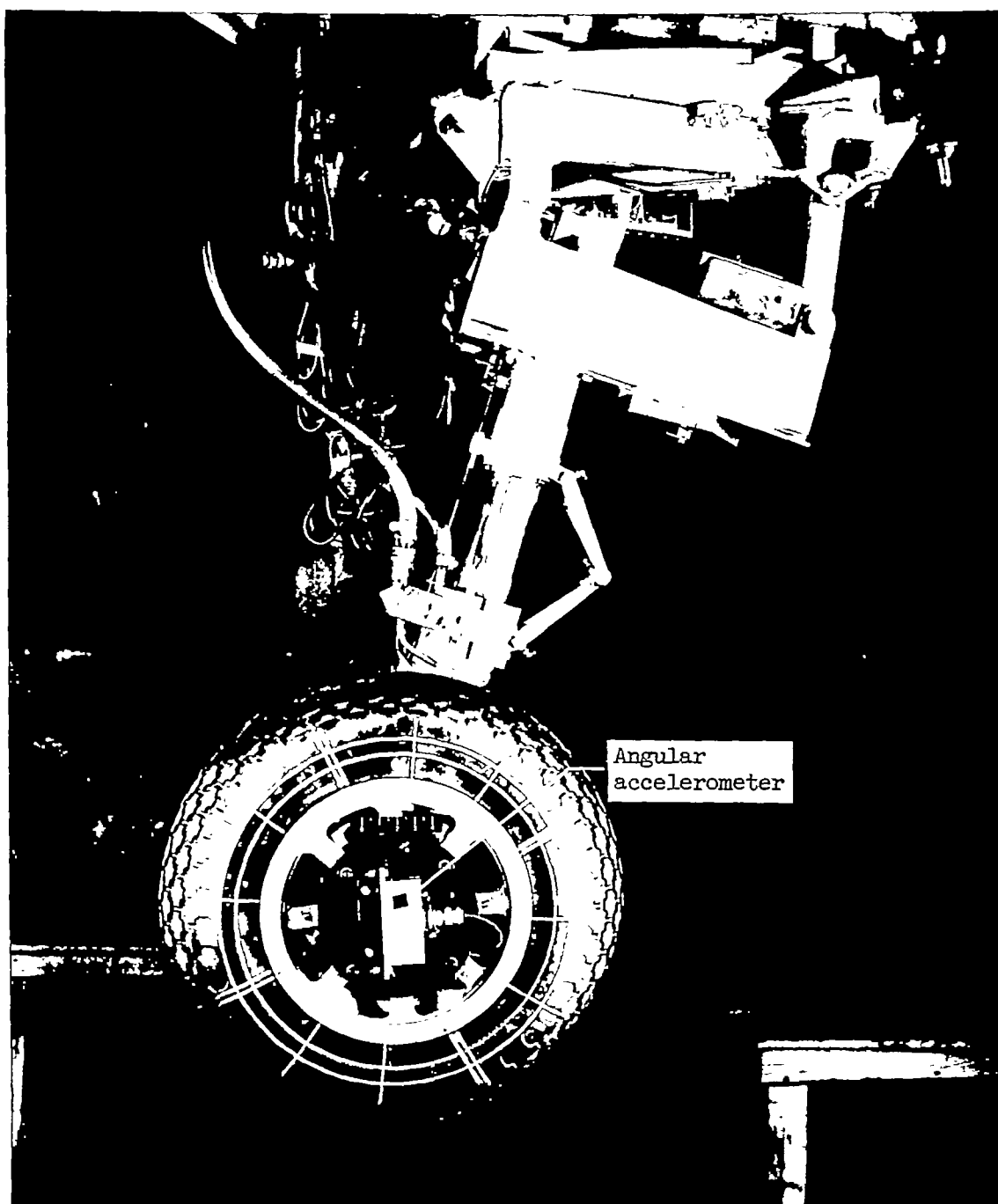
Figure 4.- Side view of landing gear and wheel.

L-78731.1
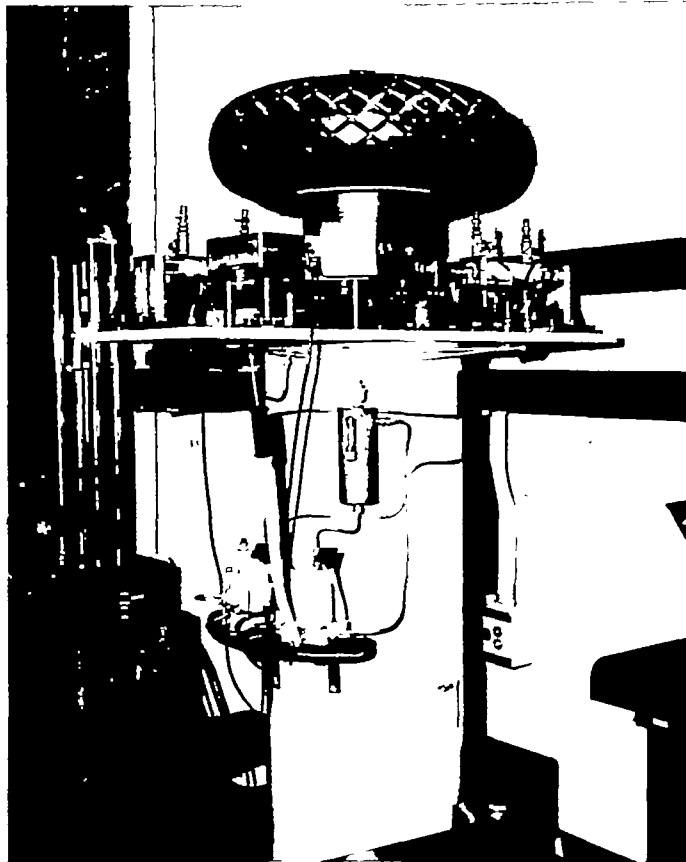
L-79565.1

Figure 5.- View of a wheel and tire mounted on torsional pendulum to
obtain moment of inertia.
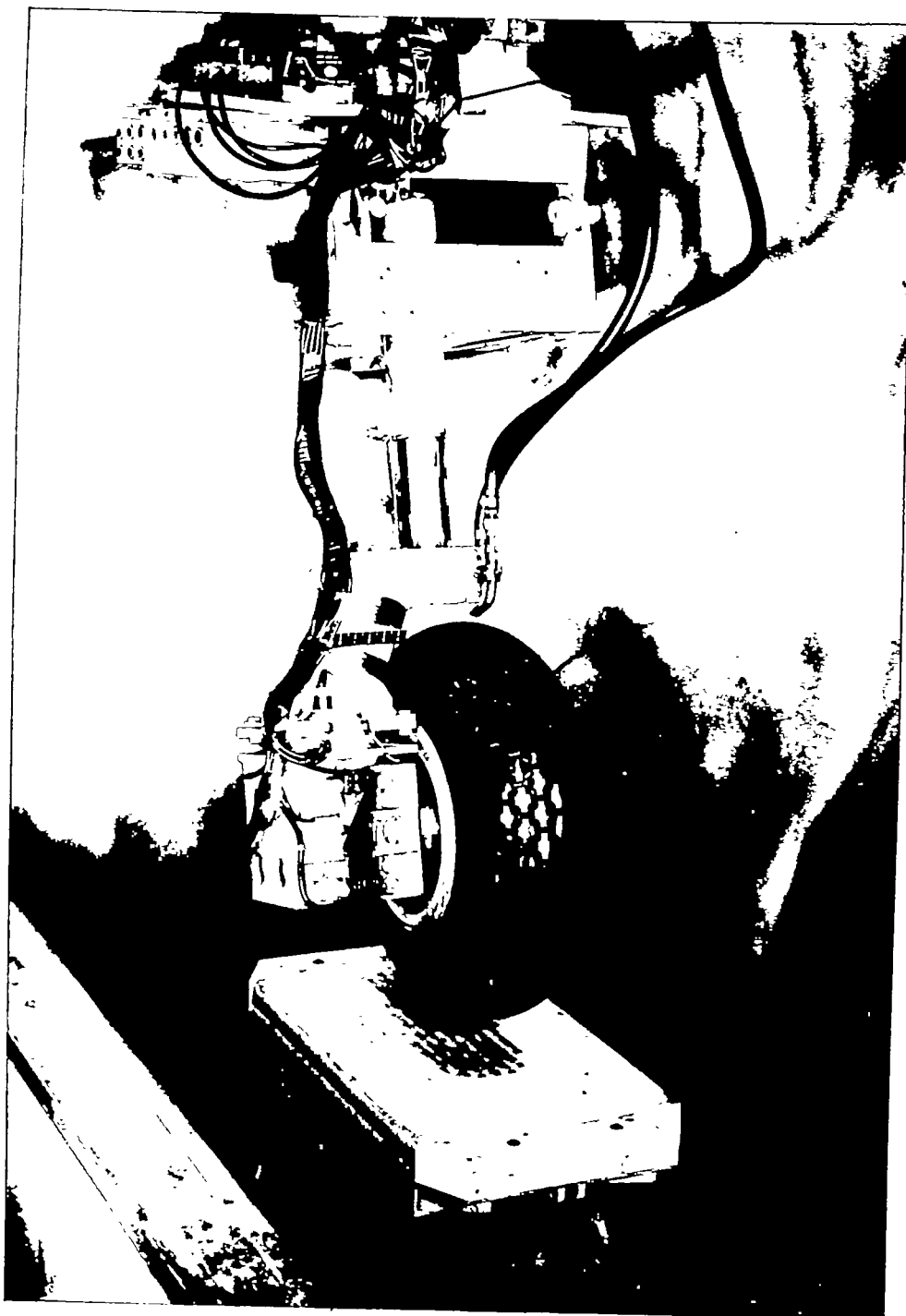
L-80403.1

Figure 6.- Front view of landing gear in position for drop testing on
the ground-reaction platform.
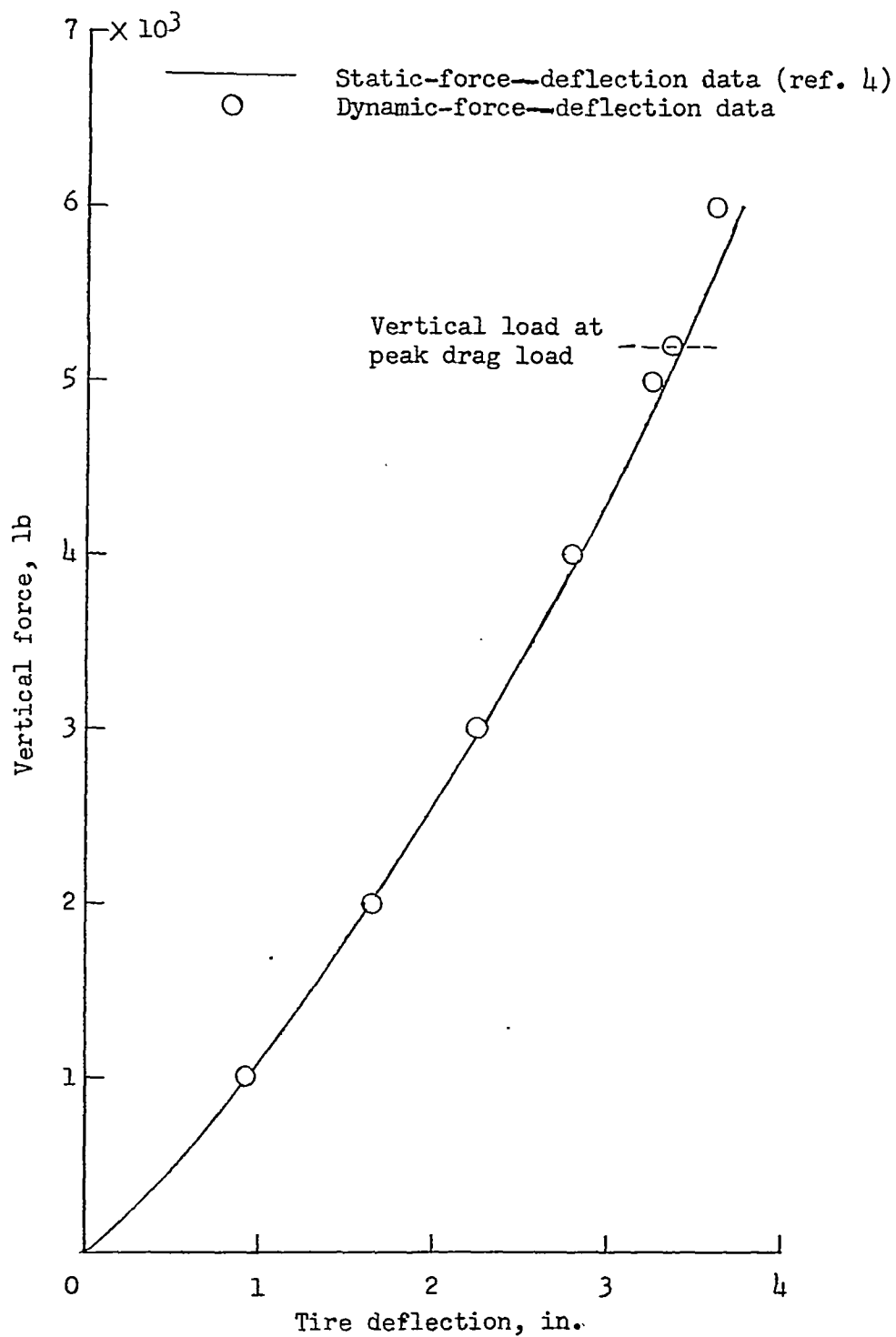
Figure 7.- Comparison of static- and dynamic-force—deflection curves
during a drop test with the wheel spinning at 721 revolutions per
minute and a vertical velocity of 7.5 feet per second.
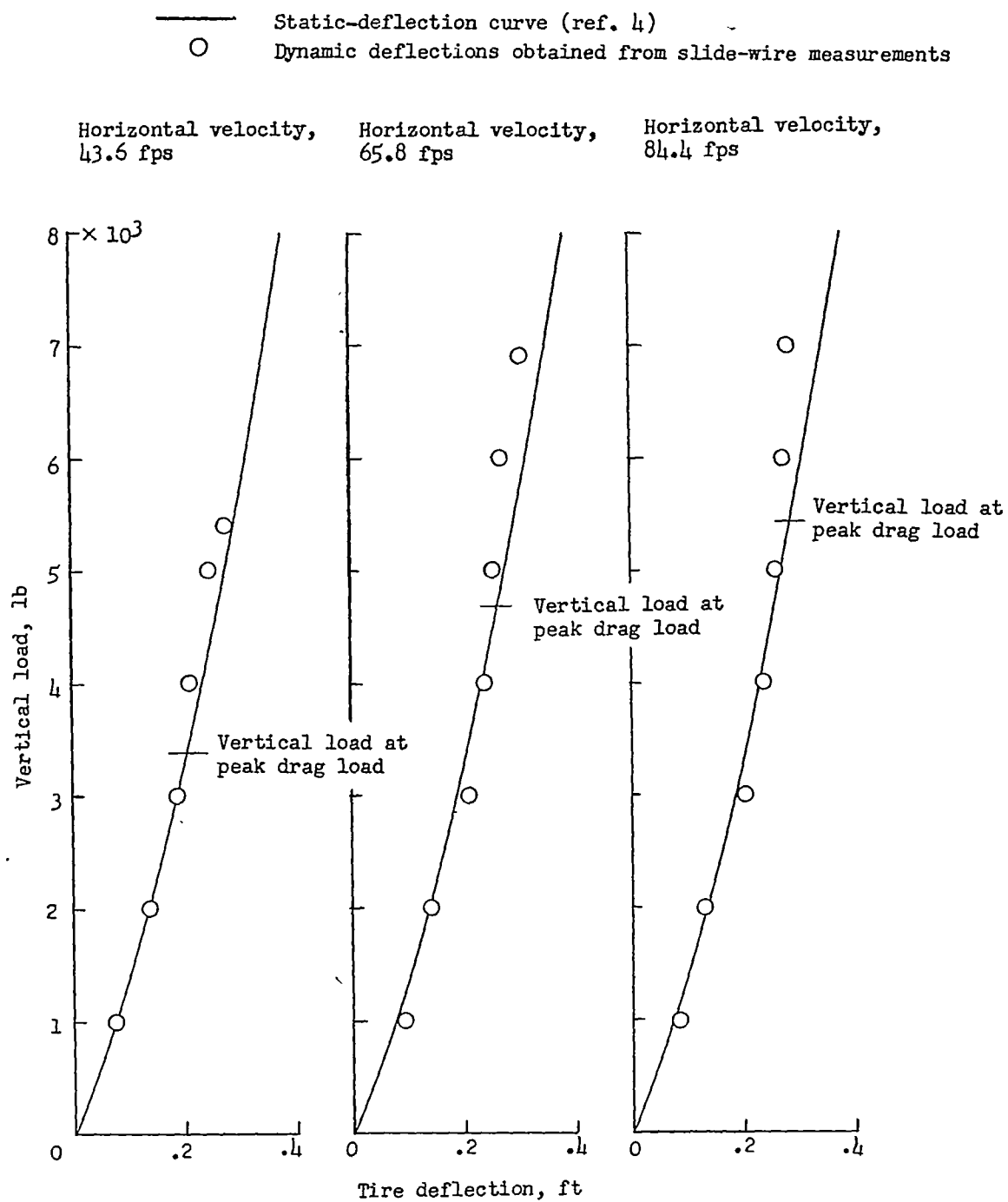
Figure 8.- Comparison of dynamic and static deflection at various horizontal velocities and a vertical velocity of 7.5 feet per second.
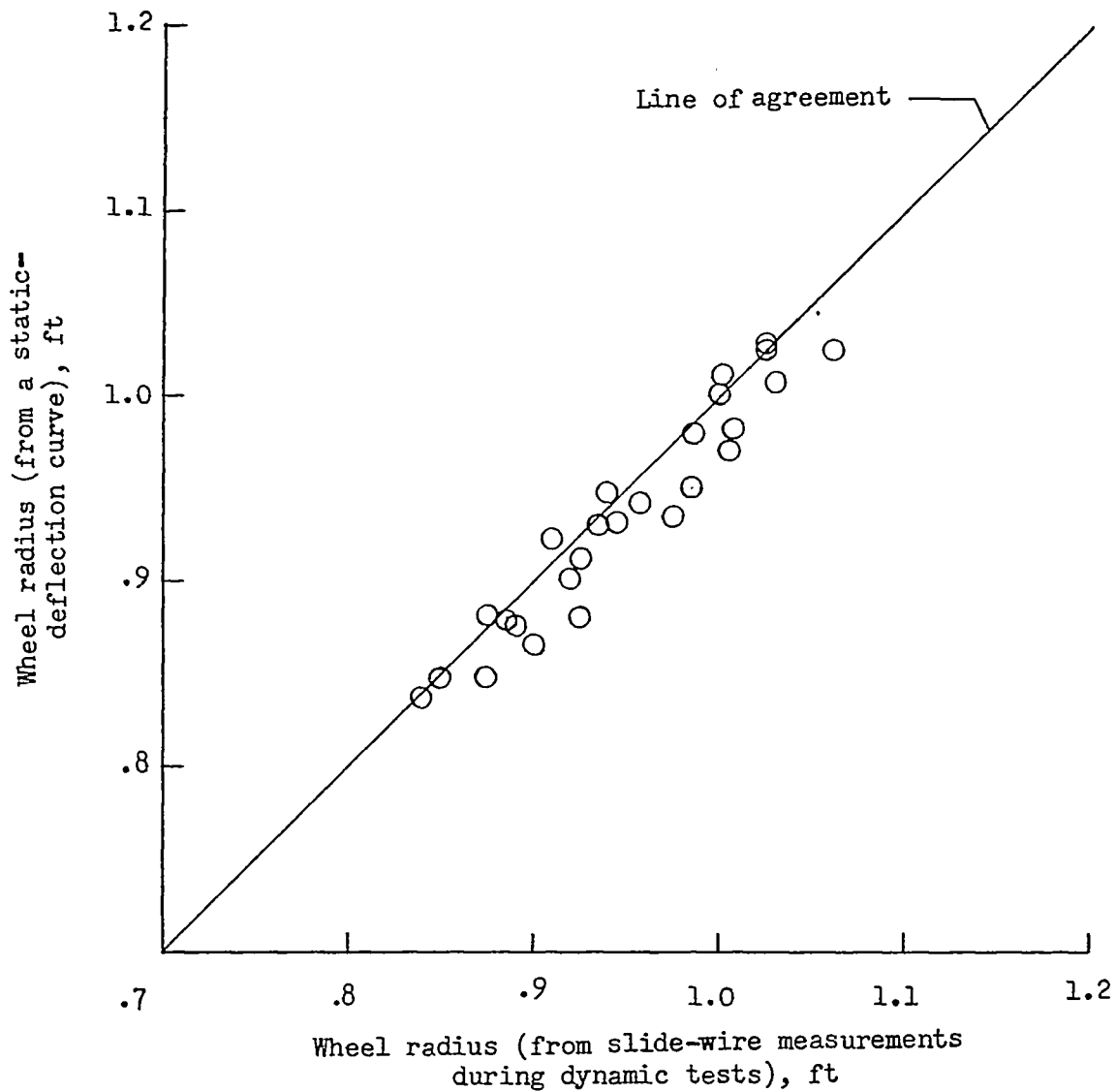
Figure 9.- A comparison of tire radii at time of peak drag load obtained
by using a static-load—deflection curve with actual measurements obtained
under dynamic conditions.
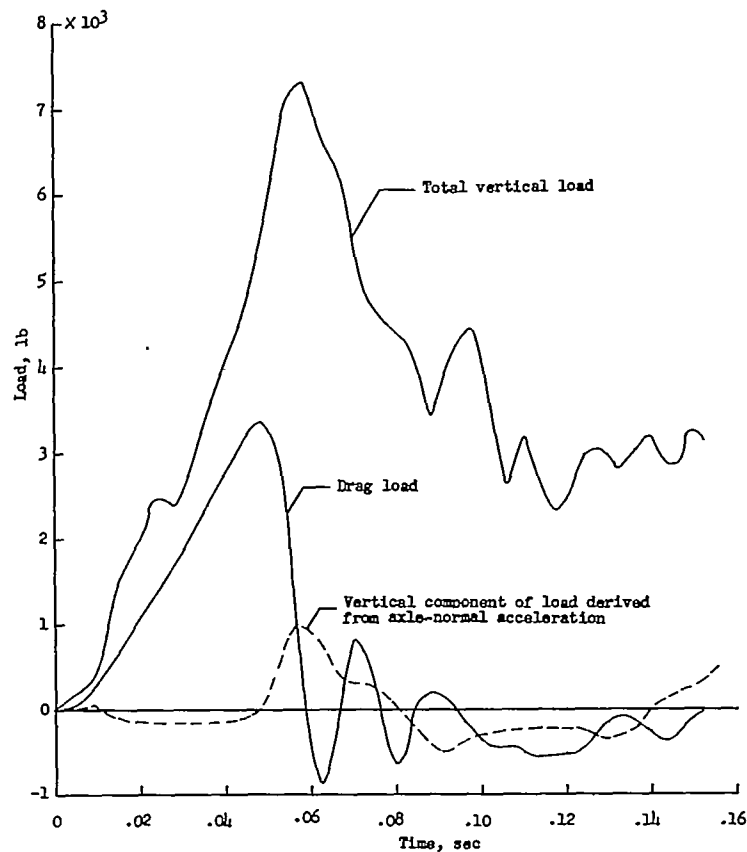
(a) Horizontal velocity, 84.4 feet per second; vertical velocity,
7.43 feet per second.
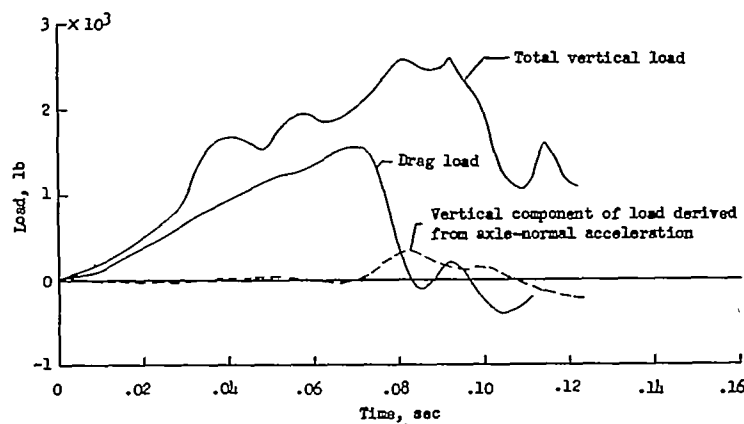
(b) Horizontal velocity, 74.8 feet per second; vertical velocity,
3.07 feet per second.

Figure 10.- Time histories of vertical load, drag load, and vertical
component of load introduced by the strut normal accelerations of the
lower mass during forward-speed landing impacts.
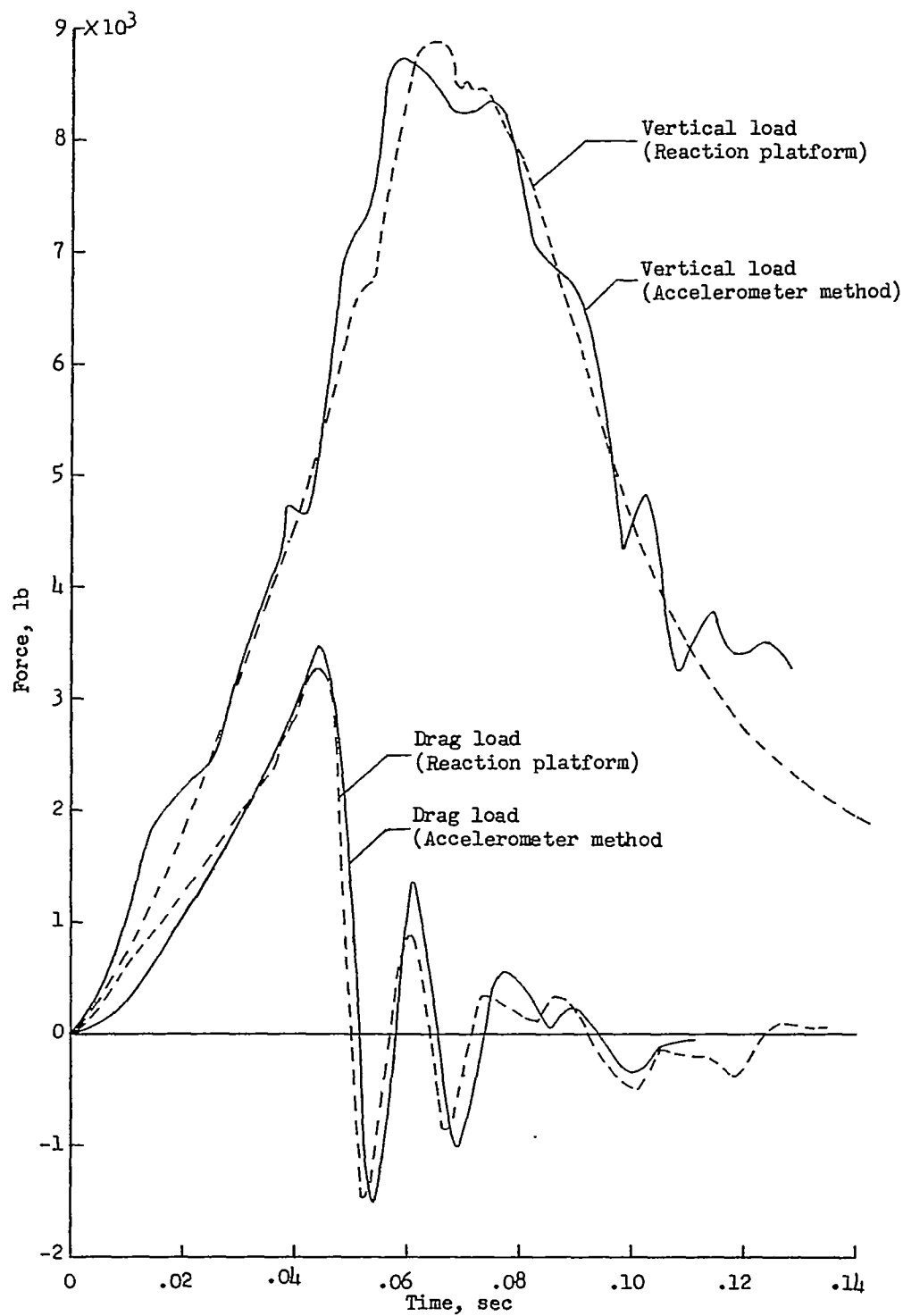
Figure 11.- A comparison of loads from the ground-reaction platform and
the accelerometers during a drop test with the wheel spinning and at
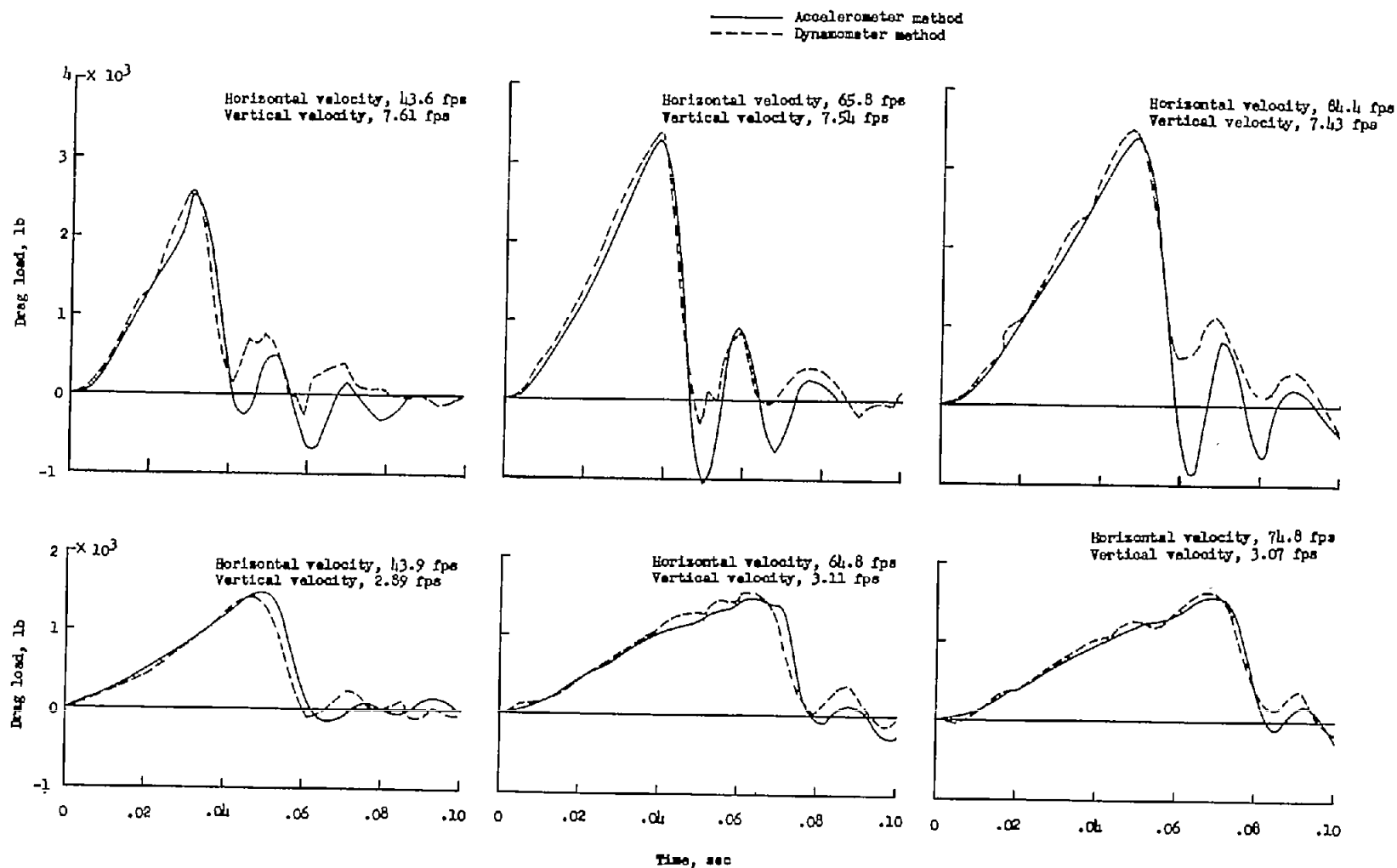a vertical velocity of 7.5 feet per second.
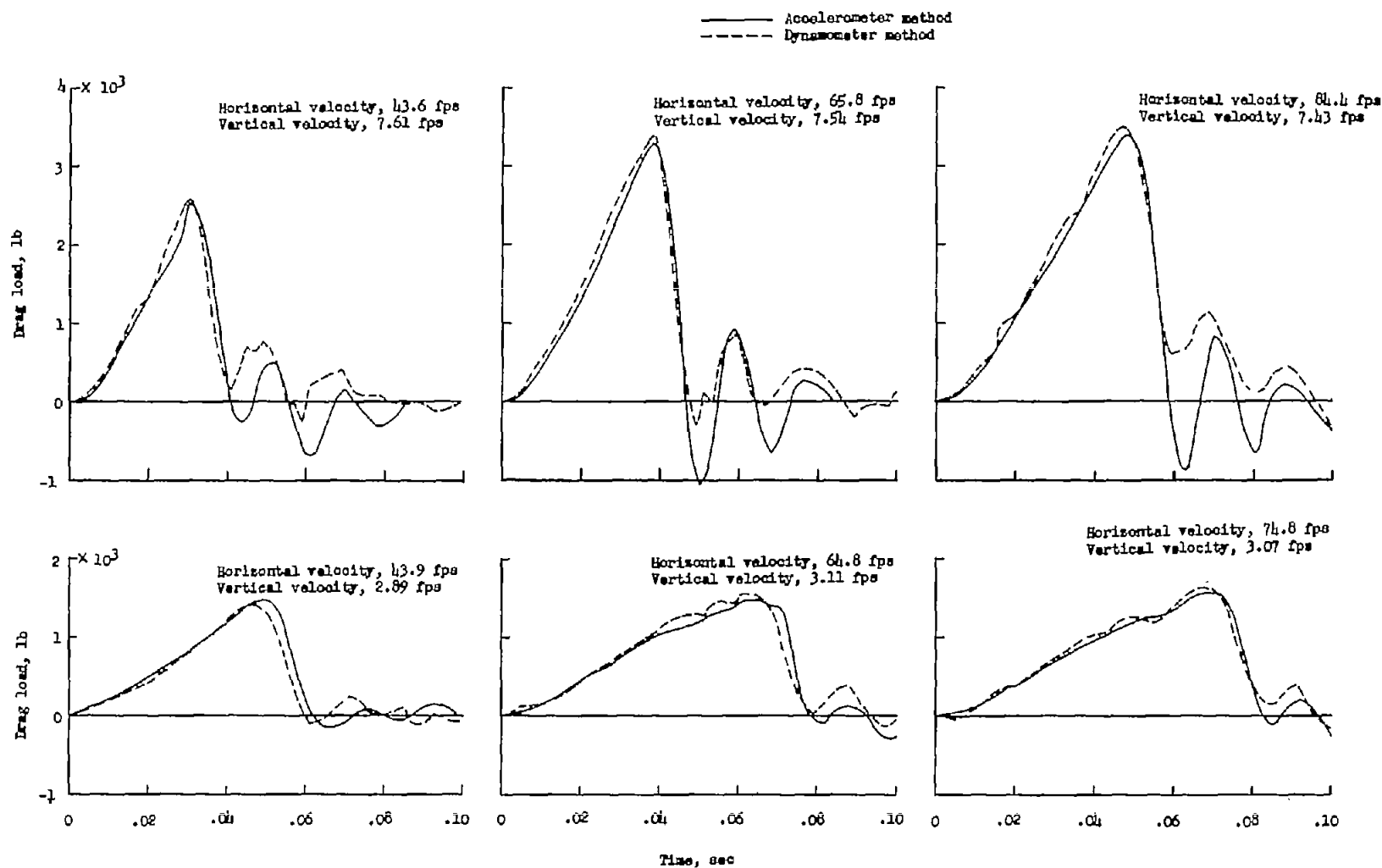
Figure 12.- Comparison of drag loads obtained from the axle dynamometer
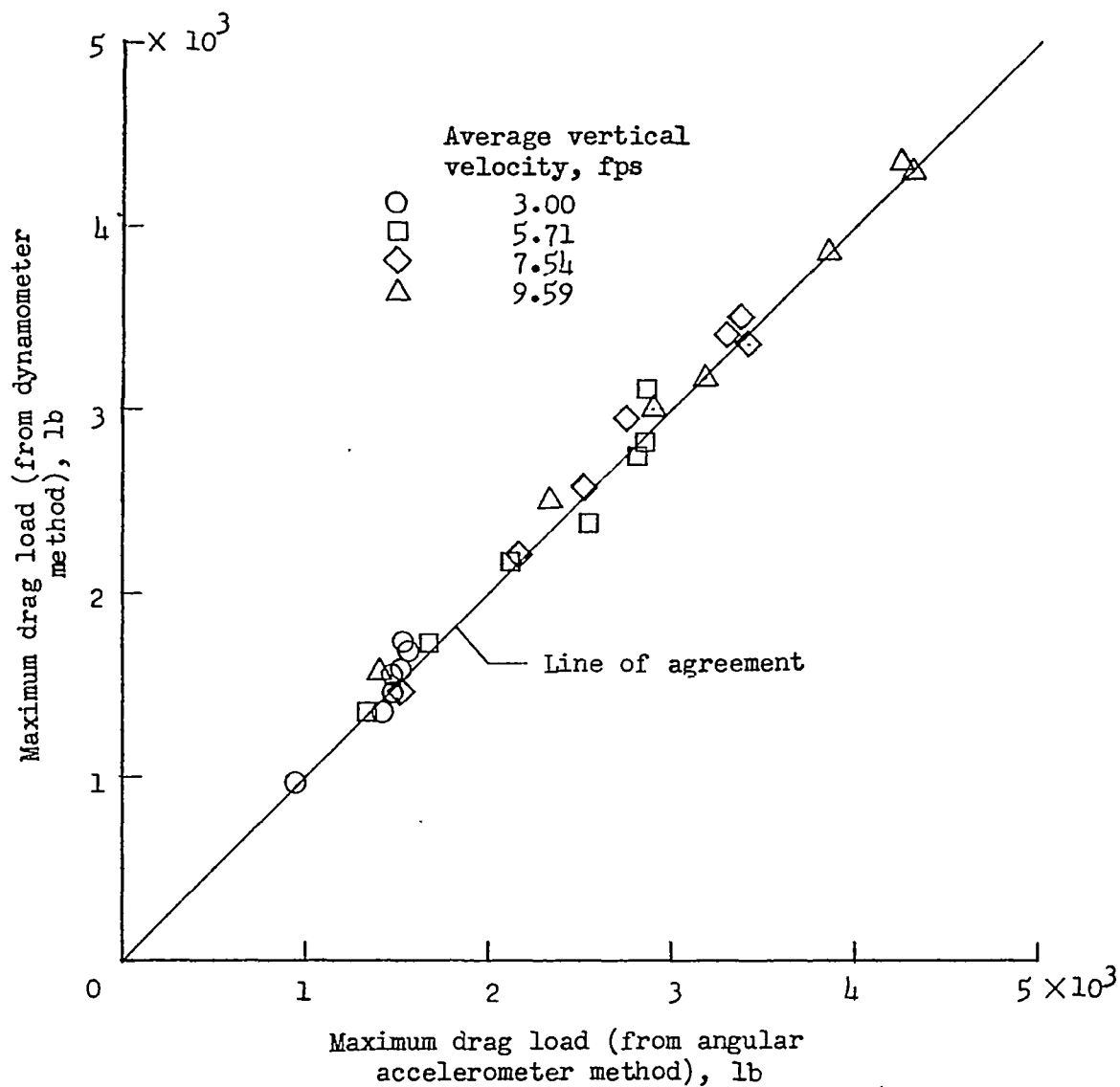and the accelerometers during forward-speed landing impacts.
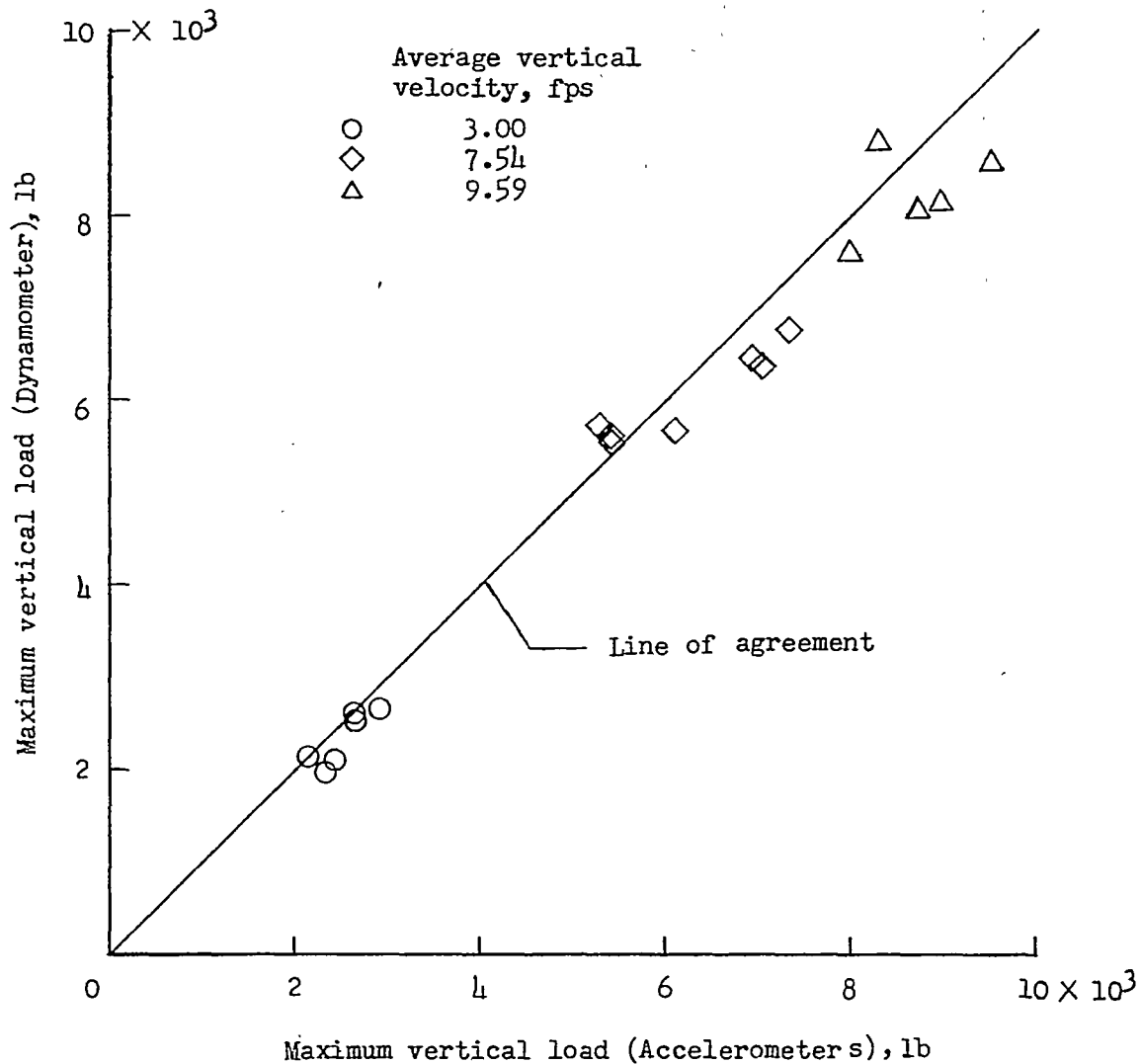
Figure 16.- A comparison of maximum vertical loads obtained from the dynamometer and accelerometers during forward-speed landing impacts at horizontal velocities from 20 to 85 feet per second.

Figure 12.- Comparison of drag loads obtained from the axle dynamometer
and the accelerometers during forward-speed landing impacts.

Figure 13.- A comparison of maximum drag loads obtained from the
dynamometer and accelerometers during forward-speed landing impacts
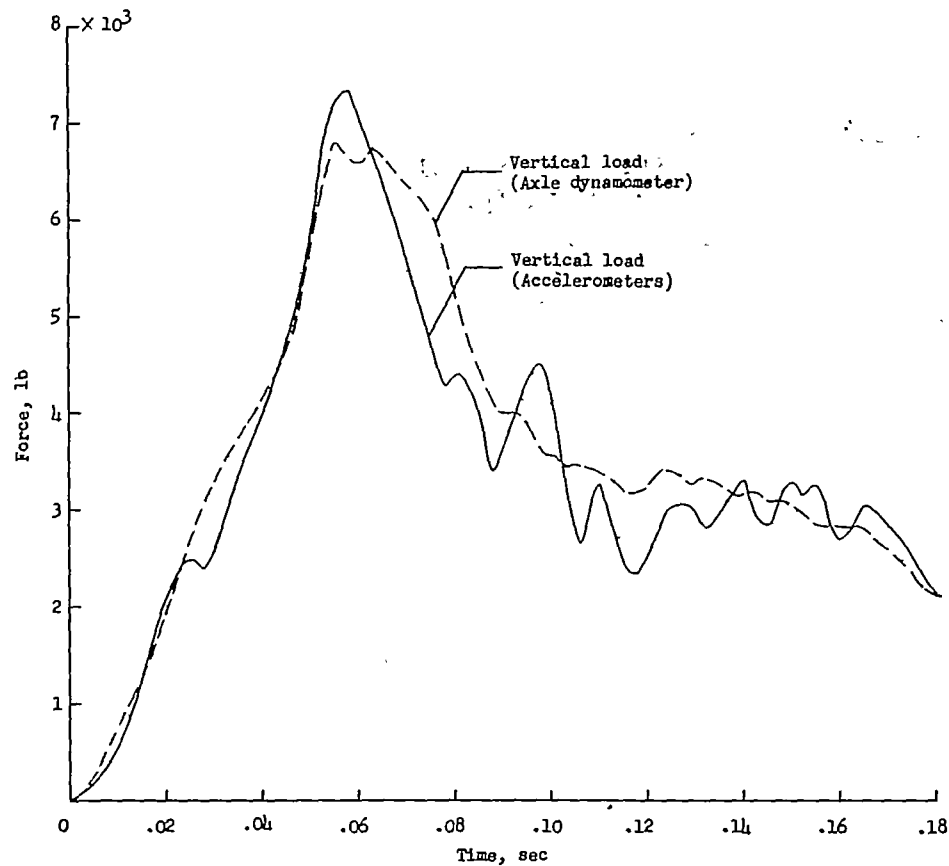at horizontal speeds from 20 to 85 feet per second.

Figure 14.- A comparison of vertical load from the axle dynamometer and
the accelerometers during a forward-speed landing impact at a hori-
zontal velocity of 84.4 feet per second and a vertical velocity of
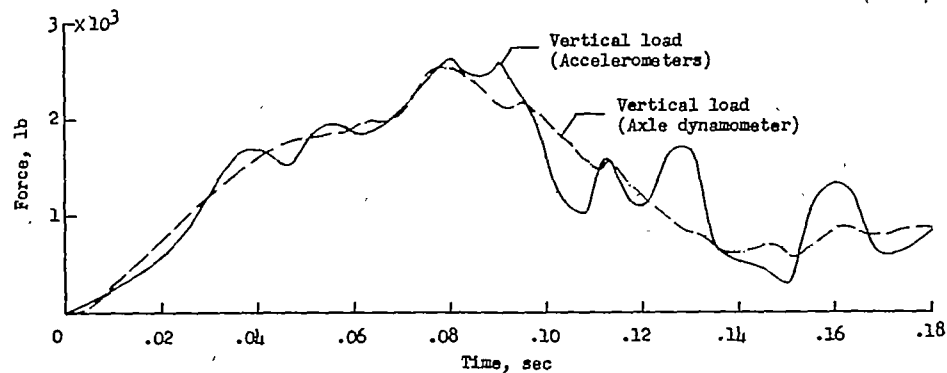7.4 feet per second.

Figure 15.- A comparison of vertical load from the axle dynamometer and
the accelerometers during a forward-speed landing impact at a hori-
zontal velocity of 74.8 feet per second and a vertical velocity of
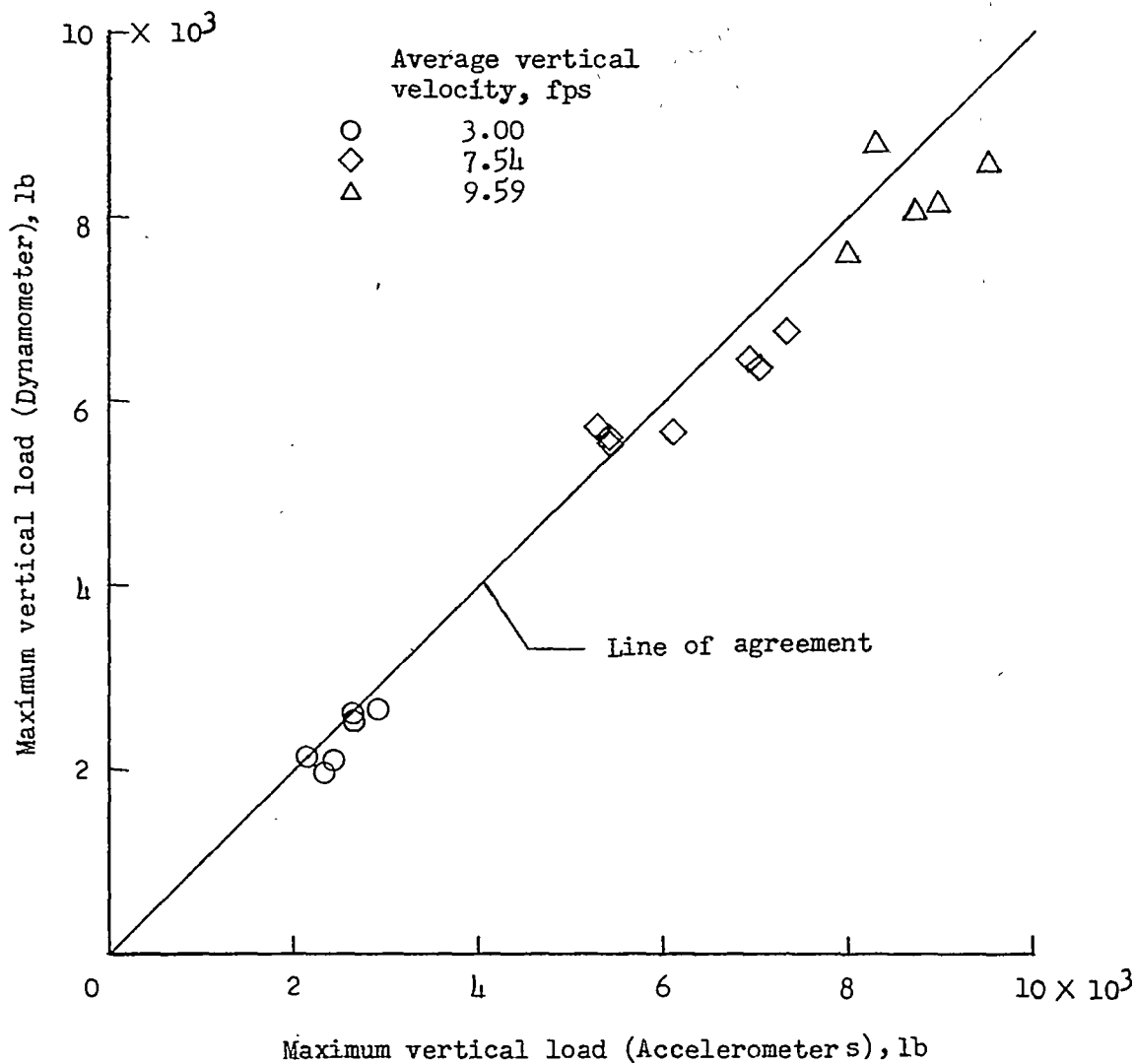3.07 feet per second.

Figure 16.- A comparison of maximum vertical loads obtained from the
dynamometer and accelerometers during forward-speed landing impacts
at horizontal velocities from 20 to 85 feet per second.